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MODELING OF A SMALL WATERSHED IN LAKE OKEECHOBEE DRAINAGE BASIN

by

Richard Z. Xue, Sr. Civil Engineer
Research Appraisal Division
Water Resources Evaluation Department
and
Joyce J. Zhang, Sr. Civil Engineer
Okeechobee Systems Research Division
Ecosystem Restoration Department

South Florida Water Management District
West Palm Beach, Florida

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MODELING OF A SMALL WATERSHED IN THE LAKE OKEECHOBEE DRAINAGE BASIN

By Richard Z. Xue,[1] Member, ASCE, and Joyce J. Zhang[2]

ABSTRACT: A stormwater runoff and pollutant model (SRPM) was developed for catchment-scale watersheds containing both urban and agricultural areas. The model was tested on a small watershed in the Lake Okeechobee drainage basin using data collected during a 33 -month period of 1989 to 1991. The performance of the model was evaluated by comparing the simulated results with outputs from a validated model CREAMS-WT. Statistical correlation of daily, monthly and annual values of observed and simulated runoff and phosphorus loads by SRPM and CREAMS-WT was analyzed. Statistical results indicated that both models performed well in predicting daily, monthly and annual runoff and phosphorus loads. Given the appropriate parameters, SRPM would also provide good prediction of hydrographs and pollutographs during storm events. Key parameters of SRPM in the simulation of hydrology and water quality components were selected for sensitivity analyses for both a typical storm event and the whole simulation period. It was found that the runoff simulation was very sensitive to the Manning roughness constant and the phosphorus load computation was sensitive to changes in the washoff parameters in both the storm event and the 33-month period, while the load calculation was more sensitive to the buildup parameters in the 33-month period than in the storm.

(KEY WORDS: Modeling, Watershed, Stormwater, Runoff, Phosphorus Load, Calibration, Sensitivity Analysis)

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[1] Sr. Civ. Engr., Dept. of Water Resource Evaluation, South Florida Water Mgmt. Dist., West Palm Beach, FL 33416

[2] Sr. Civ. Engr., Dept. of Ecosystem Restoration, South Florida Water Mgmt. Dist., West Palm Beach, FL 33416

INTRODUCTION

Stormwater runoff and the associated pollutant loads have gained great attention in urban planning and agricultural pollution control. Evaluation of alternative scenarios in urban development and agricultural management is needed to assess the environmental impacts on existing watersheds due to changes in land use and other activities, and to design water quality and hydrologic systems (Arnold et al. 1995). A watershed model is needed for such evaluations as a tool to predict future runoff and water quality impacts on a receiving water and to assess urban stormwater management alternatives (Greene and Cruise 1995). While a number of possible models exist, they leave much to be desired for predicting the effects of management scenarios.

Modeling the quantity and quality of stormwater runoff is difficult due to variations in land use, human activities, and meteorological conditions (Haster and James 1994). A few existing watershed models are available to simulate stormwater runoff and its pollutant loads for different applications. The U.S. EPA (1992) defined three classes of watershed-scale models as simple, mid-range, or detailed. Simple methods apply simplistic, statistical, and/or empirical equations to simulate annual averages of runoff and pollutant loads. These models require historical monitoring data and their applications are usually limited to the areas for which the models were developed and to similar watersheds (U.S. EPA 1992). Mid-range models describe the relationship of pollutant loadings to hydrologic and erosion processes on monthly or seasonal bases. These models consider neither adsorption, degradation and transformation processes of pollutants nor pollutant transport within and from the watershed (U.S. EPA 1992). The mid-range models can be applied for relative comparison analysis for watershed planning decisions. Both simple and mid-range models are not applicable to this study due to the limited predictive capability of surface runoff and water quality.

Detailed models, such as ANSWERS, DR3M-QUAL, HSPF, STORM, SWMM, and SWRRBWQ, simulate the physical hydrologic and pollutant transport and transformation processes in watershed areas at a small time step to account for effects of storm events (U.S.

EPA 1992). Among these detailed models, ANSWERS and SWRRB were developed for agricultural areas only; DR3M-QUAL, STORM, and SWMM were designed for urban areas; and HSPF is only model which can be applied to both urban and agricultural areas.

The Hydrological Simulation Program - FORTRAN (HSPF) simulates hydrolysis, oxidation, photolysis, biodegradation, volatilization and sorption processes to describe pollutant generation, transformation and transport from watersheds to and within receiving water bodies (U.S. EPA 1993). Three distinct categories such as pervious lands, impervious lands, and channel streams are considered in HSPF. HSPF has drawbacks, however, including that the model requires extensive input data, highly trained personnel and team efforts and therefore it is not suitable for the kind of evaluation being considered in this study. The Storm Water Management Model (SWMM) developed by the U.S. EPA (Huber et al. 1987) has been widely applied in urban areas. The model allows users to specify up to ten pollutants of interest for simulation. With some modification, SWMM could be used for this study. However, SWMM also requires a comprehensive database and an extensive modeling effort. In addition, the SWMM model runs relative slowly with a small time step.

The Chemicals, Runoff, and Erosion from Agricultural Management Systems - Water Table (CREAMS-WT) (Heatwole 1986) and the Field Hydrologic and Nutrient Transport Model (FHANTM) (Tremwel 1992), both developed for applications in south Florida's agricultural fields, were also a concern for this study. The two models were evaluated and tested in different locations in Lake Okeechobee watersheds (Zhang et al. 1995). Both models, however, were not selected for this study for two reasons: 1) they do not provide hourly simulation results, and 2) they are field-scale models.

The overall objective of this study was to develop a catchment-scale model to assess urban and agricultural stormwater management alternatives. Specifically, the simulation model should be applicable to predict stormwater quantity and quality on either a storm event or a long term basis (e.g., months or years). The model should generate runoff and pollutant loads at an hourly time step in order to link with the Best Management Practices Assessment Model

(BMPAM) (Xue 1995). In this paper we introduce the Stormwater Runoff and Pollutant Model (SRPM), developed to simulate watershed runoff and the associated pollutant loads in both agricultural and urban areas. Most hydrology and water quality simulation algorithms used in SRPM were adapted from the SWMM model due to its flexibility to simulate different land use types and user-defined water quality constituents. A reservoir flow routing method (Linsley and Franzini 1964) was used in SRPM to speed up simulation time, instead of using the Newton-Raphson technique to solve nonlinear equations for hydrology simulation in SWMM (Nix 1994). This model was calibrated using data collected from a small catchment area in south Florida. Simulation results were also compared with outputs from a validated model CREAMS-WT.

MODEL DESCRIPTION

SRPM is a catchment-scale hydrology and water quality model which simulates storm-related surface runoff and the associated pollutant loads in a catchment or watershed. It was developed for watershed analyses in urban and agricultural areas. The model was written in FORTRAN and can be executed on both PC DOS and UNIX operating systems. SRPM is a continuous simulation model with an hourly time step. It provides results for both individual storm events and a long-term simulation. The outputs of simulated runoff, pollutant loads and concentrations are in the standard time series ASCII formats that can be easily read by other programs for further analyses.

Hydrology Simulation

SRPM model allows users to simulate up to ten (10) sub-catchments in each application run. Each sub-catchment represents a different land use type or percentage of pervious and impervious areas. The algorithm used in hydrologic simulation is similar to that used in the RUNOFF block of SWMM (Huber et al. 1987). A sub-catchment is treated as a nonlinear reservoir with consideration of the processes of precipitation, evapotranspiration (ET), infiltration, depression storage, percolation and surface runoff.

A simple hydrologic method of flow routing was presented by Chow (1959) and by Linsley and Franzini (1964):

$$\frac{S_2-S_1}{\Delta t}=\frac{I_1+I_2}{2}-\frac{O_1+O_2}{2} \tag{1}$$

where S_2 = storage in the reservoir at the end of routing period (m^3); S_1 = storage in the reservoir at the beginning of routing period (m^3); Δt = routing period (sec); I_1 = instantaneous inflow at the beginning of routing period (m^3/s); I_2 = instantaneous inflow at the end of routing period (m^3/s); O_1 = instantaneous outflow at the beginning of routing period (m^3/s); and O_2 = instantaneous outflow at the end of routing period (m^3/s). Precipitation is the only inflow component in SRPM while the outflow includes evapotranspiration, infiltration, percolation and surface runoff. Equation (1) can be rewritten as the following equation after grouping the unknowns and knowns on the each side of the equation (Huber et al. 1987):

$$\frac{1}{2}O_2\Delta t+S_2=\frac{1}{2}(I_1+I_2)\Delta t+(S_1-\frac{1}{2}O_1\Delta t) \tag{2}$$

The variables on the right hand side of Equation (2) are known for a given time step. The two unknowns O_2 and S_2 on the left hand side of the equation can be solved after the relationship between O_2 and S_2 is determined. In the hypothetical reservoir, the geometric dimensions of the reservoir and the outflow structure data are given. Therefore, the relation of O_2 and S_2, each of which is a function of storage depth, can be determined (Huber et al. 1987). This reservoir routing method was applied in SRPM for the simulation of the overland flow.

Manning's equation is used for the runoff estimation in SRPM. The equation calculates overland flow velocity by using the parameters of hydraulic radius, slope and the Manning roughness constant. The roughness constant represents the land surface condition and the land use type of a specific sub-catchment. The overland flow (i.e. surface runoff) occurs only when water depth in the hypothetical reservoir exceeds the reservoir capacity defined by the maximum depression storage (Nix 1994):

$$Q = \frac{W}{n}(d-d_p)^{5/3}S^{1/2} \tag{3}$$

where Q = runoff flow rate from a catchment (m^3/s); W = width of overland flow (m); n = Manning roughness constant (dimensionless); d = depth of water on the catchment (m); d_p = depth of maximum depression storage (m); and S = slope of the catchment (m/m).

A three-parameter empirical infiltration model, the Horton Model, has been widely used to calculate the infiltration capacity into soil. The Horton model expresses that the infiltration capacity is equal to the maximum infiltration rate at the beginning of a storm event and then is reduced to a low constant rate as the soil becomes saturated (Rawls et al. 1993). The infiltration capacity calculated by the Horton model is often less than the actual infiltration capacity because typical values for infiltration parameters are often greater than typical rainfall intensities. The integrated form of Horton's equation (Huber et al. 1987) was selected in SRPM to solve this problem:

$$F(t_p) = \int_0^{t_p} f(t)\,dt = f_\infty t_p + \frac{(f_0 - f_\infty)}{\alpha}(1 - e^{-\alpha t_p}) \tag{4}$$

where $F(t_p)$ = cumulative infiltration at $t = t_p$ (m); t_p = time at the end of simulation step (sec); f(t) = infiltration capacity into soil at $t = t_p$ (m/s); f_∞ = minimum or ultimative infiltration rate (m/s); f_o = maximum or initial infiltration rate (m/s); α = decay coefficient (1/sec). The regeneration or recovery of infiltration capacity during dry weather is considered for continuous simulation by applying same approach as in SWMM. This infiltration simulation approach allows users to define the proper values of f_∞ and f_o based on the areas of simulation. The f_∞ value in south Florida is usually higher than that observed in other areas in the U.S.A. due to the dominance of sandy soils.

Observed pan evaporation records are used to calculate water depletion by the process of evapotranspiration in watersheds. Actual evapotranspiration is calculated based on the pan evaporation values by multiplying an ET coefficient. SRPM allows users to provide monthly ET coefficients to account for seasonal variations of the evapotranspiration in a watershed. The estimated evapotranspiration value is subtracted from the calculated infiltration rate to estimate percolation rate which is used to calculate the water loss into the groundwater.

Water Quality Simulation

Water quality simulation in watersheds is difficult due to various physical and chemical processes governing fate and transport of pollutants, the effects of rainfall and watershed characteristics, and the land use practices (Haster and James 1994). Both regression equations and deterministic models have been used for the simulation of pollutant transport. For SRPM, a deterministic model that includes pollutant build-up and washoff components was selected for the simulation of stormwater pollutant loads. The SRPM model allows users to define water quality constituents to be simulated.

The concept of "buildup" was first introduced to describe the accumulation of dust and dirt and associated pollutants on urban street surfaces in the late 1960s (ASCE and WEF 1992). Thereafter, the buildup concept (as well as washoff concept) has been included in several watershed models such as SWMM, HSPF, STORM, USGS and SLAMM (U.S. EPA 1992). Buildup is defined as the pollutant accumulation during the dry-weather periods between storms. The buildup process is a combination of atmosphere deposition, wind erosion, street cleaning or other human activities. An exponential function was selected for SRPM similar to the one included in SWMM (Huber et al. 1987) for the simulation of the buildup of water quality constituents:

$$P_{buildup}=P_{limit}(1-e^{-\alpha t}) \tag{5}$$

where $P_{buildup}$ = amount of pollutant accumulation (kg); P_{limit} = maximum value of pollutant buildup (kg); α = pollutant buildup rate (1/sec); and t = time (sec). During the continuous simulation, buildup will not occur during the wet-weather time steps unless runoff is less than 0.00127 cm/hr (0.0005 in/hr) (Huber et al. 1987).

Washoff is defined as the pollutant removal process associated with runoff during storm events. Similar to the exponential buildup equation, the exponential washoff equation describes the relationship between the initial amount and the cumulative amount washed off during storm events. By using the average power of runoff over the simulation time step, a modified washoff equation (Huber et al. 1987) was applied in SRPM:

$$P_{remain}(t+\Delta t) = P_{remain}(t)\, e^{-\beta \frac{1}{2}[r(t)^n + r(t+\Delta t)^n]\Delta t} \tag{6}$$

where P_{remain} = amount of pollutant remaining in a catchment (kg); β = washoff coefficient (dimensionless); Δt = simulation time step (sec); $r(t)$ = runoff rate at time t (cm/hr); $r(t+\Delta t)$ = runoff rate at time $t+\Delta t$ (cm/hr); n = washoff power factor (dimensionless).

MODEL CALIBRATION AND VALIDATION

A newly-developed continuous simulation model is normally tested and validated by applying calibration and verification procedures. Usually, three or more consecutive years of observed data are used to calibrate the model and the parameter set is then verified by using an independent series of observed data of several years or more (Fontaine 1995). A different approach was used here due to the limited field data collected during the 33-month period, i.e. the entire data set was used to calibrate the SRPM model. The calibrated results were then compared to simulation results from CREAMS-WT conducted by Zhang et al. (1995). The performance of SRPM was validated by means of statistical correlation analyses of daily, monthly and annual values of measured and simulated runoff and the pollutant loads.

Watershed Description

A small catchment area located at W. F. Rucks Dairy in the Lake Okeechobee drainage basin in south central Florida was selected for this modeling study because intensive data on runoff and phosphorus transport was collected in this area from April 1989 to December 1991 (Tremwel 1992). The W. F. Rucks site has a drainage area of 38,850 m^2 and contains spodosol soils including Myakka, Immokalee, and Pomello, which are the dominant soil types for the entire region north of Lake Okeechobee (Campbell et al. 1988). The site was used to graze cattle at low densities for approximately the first half of the 33-month study period, but was used for beef production for the rest of the period (Tremwel 1992). The detailed description of the study area and the observed data set including precipitation, evaporation, runoff and phosphorus loads was presented by Tremwel (1992) and Zhang et al. (1995).

Model Results and Analysis

Observed and simulated daily runoff and phosphorus loads from SRPM and CREAMS-WT are plotted in Fig. 1. Generally, simulated results from SRPM compared with observed values similar to results from CREAMS-WT. However, the simulated daily results from both models were either underpredicted or overpredicted at certain days (Figs. 1a and 1b).

It can be seen that the simulated monthly runoff from SRPM and CREAMS-WT predicted the monthly runoff values fairly well except the overpredicted period of May through August, 1989 and the underpredicted month of August, 1991 (Fig. 2a). Compared with the CREAMS-WT model, SRPM performed well in simulating the monthly phosphorus loads except for the months of August (Fig. 2b). It is difficult to predict various rainfall-runoff-pollutant load relationships in a same month (i.e. August in this study) at different years because SRPM uses mean monthly adjusted pollutant buildup and washoff coefficients during the whole simulation period. Better calibrated results will obtain if a longer historic data record including a few dry and wet years are available.

Simulated annual results indicated that both models performed closely in simulating annual runoff and phosphorus loads, except for the results of annual phosphorus loads in 1991 (Fig. 3). The simulated total runoff of 52.9 cm from SRPM (percent error of -0.7) or 52.5 cm from CREAMS-WT (percent error of -1.5) in the 33-month period matched well with the observed total runoff of 53.3 cm (Table 1). Similarly, the simulated total phosphorus loads of 2.99 kg/ha from SRPM (percent error of 12.7) or 3.32 kg/ha from CREAMS-WT (percent error of 25.4) were close to the observed total phosphorus loads of 2.66 kg/ha (Table 1).

Validation Results

Statistical correlation analyses were conducted to validate the SRPM model. The correlation analyses were performed using daily, monthly and annual runoff and phosphorus loads simulated from SRPM and CREAMS-WT. Tables 1 through 3 present the statistical analysis results of the observed and predicted daily, monthly and annual runoff and phosphorus loads, respectively. The statistical results indicated that SRPM had slightly better agreement between daily observed and simulated values than did CREAMS-WT by comparing R^2, *regression slope*, and *Pearson correlation coefficient* (Table 1). This can be explained by the fact that SRPM simulates hourly effects during storm events while CREAMS-WT calculates daily runoff and pollutant loads which is designed for a long-term simulation.

Simulation results demonstrated both models predicted well in terms of monthly runoff and phosphorus loads (Table 2). CREAMS-WT performed better in simulating monthly runoff than SRPM while SRPM performed better in predicting monthly phosphorus loads than CREAMS-WT in terms of R^2, regression slope, and pearson correlation coefficient (Table 2). It can be seen from Table 3 that a strong agreement between the annual observed and simulated runoff and phosphorus loads was obtained with the Pearson correlation coefficient greater than 0.95 and R^2 greater than 0.90 for both models.

SENSITIVITY ANALYSES

Two types of sensitivity analyses were conducted by performing multiple simulations in SRPM. First, the sensitivity of the runoff hydrographs and volumes to surface characteristics was analyzed. Secondly, the sensitivity of the pollutographs and pollutant loads to surface characteristics and pollutant buildup and washoff coefficients was examined. The sensitivity analyses of the hydrographs and pollutographs were conducted for a typical storm event in the study area, while the sensitivity analyses of the runoff volumes and pollutant loads were conducted for the whole simulation period. Since all parameters used for the sensitivity analyses are monthly input values in SRPM, the parameter was increased by 50 percent or decreased by 50 percent only in the month when the typical storm event occurred (i.e., October) for each sensitivity analysis simulation described below. A precipitation hyetograph was plotted within all runoff hydrographs and pollutographs in the selected storm event for comparative purposes.

Sensitivity of Hydrographs and Pollutographs

To examine the sensitivity of the runoff response to the surface characteristics, two key parameters (i.e., Manning roughness constant n and depth of maximum depression storage) in SRPM were analyzed. It can be seen that the peak of the hydrograph tended to decrease and the shape of the hydrograph changed as the n value was increased (Fig. 4a). This finding is very similar to the results of a sensitivity analysis on the functional relationship between the hydrograph characteristics and the roughness constant conducted by Greene and Cruise (1995). They observed that the hydrograph shape changed to the similar rainfall excess pattern when the Manning roughness constant was decreased. A delay of predicted runoff peak was observed, compared to precipitation hyetograph peak (Fig 4a). This behavior also shows that the model performs as one would expect.

Similar to the previous result, the hydrograph peak was decreased when the maximum depression depth was increased (Fig. 4b). The runoff volume was also decreased as the depression depth was increased during the storm event. This is because surface runoff occurs only when the water depth in the watershed exceeds the maximum depression depth (Nix 1994). As the maximum depression depth is increased, the water in the maximum surface storage such as ponding, surface wetting and interception, is increased and the runoff volume is decreased. Changes in values of the evapotranspiration coefficient caused no impact on hydrographs (Fig. 4c). This was because no evapotranspiration was observed during storm events, especially during the heavy rainfall event occurred on October 10, 1989.

To examine the effects of pollutant buildup and washoff coefficients on the pollutographs and total pollutant loads, four input parameters (i.e., maximum buildup value, buildup rate, washoff coefficient and washoff power factor) were selected for the sensitivity analyses. Figs. 5a and 5b show the same pattern when the pollutograph peak or the volume of phosphorus loads increased as the maximum buildup value or the buildup rate increased. However, the changes observed during the storm event are not significant because the pollutant buildup processes do not occur during storms (Huber et al. 1987).

A significant change in the pollutograph peak and the volume of phosphorus loads was observed in Fig. 5c since the washoff processes occur only during storms (Huber et al. 1987). As the washoff coefficient increased, the peak of the pollutograph and the phosphorus loads occurring in the storm event increased. However, no trend was observed in Fig. 5d because the amount of pollutant washoff is a function of rainfall intensity. For values of runoff rate $r < 2.54$ cm/hr (1.0 in/hr), the pollutant loads may increase with increasing runoff rate during the middle of a storm by increasing the washoff power factor; however, a larger value of the washoff power factor generally yields lower pollutant loads (Huber et al. 1987). Huber et al. (1987) suggested that a power factor value less than one should used if the concentration of a dissolved constituent is decreased strongly with increasing flow rate; otherwise, the power factor should be greater than one.

Sensitivity of Total Runoff Volume and P Loads

The sensitivity analysis of total runoff volume in the 33-month simulation period to changes in the Manning roughness constant, maximum depression depth, and ET coefficient demonstrated that the total runoff volume was strongly decreased as the roughness constant or the maximum depression depth was increased (Fig. 6a). The increase of the ET coefficient resulted in the slightly decreased total runoff because the ET coefficient was varied only in the month of October during the whole simulation run. If the ET coefficient is increased in each month, more reduction of total runoff is expected because evapotranspiration occurs mostly in summer season. A lysimeter study of evapotranspiration in South Florida indicated that ET had higher values from April to September than those from October to March (Abtew and Obeysekera

1995). Compared to the sensitivity analysis results of the depression depth to the hydrograph (Fig. 4b), Fig. 6a indicated that cumulative surface runoff was more sensitive to maximum depression depth than storm event hydrograph.

The sensitivity analyses of total phosphorus loads response to various values of the maximum buildup value, buildup rate, washoff coefficient and washoff power factor showed that the phosphorus load was increased as the maximum buildup value, the buildup rate or the washoff coefficient was increased (Fig. 6b). Compared with the other parameters, total phosphorus load was less sensitive to changes in the washoff coefficient parameter and total load decreased as the washoff power factor increased.

SUMMARY AND CONCLUSIONS

A stormwater runoff and pollutant model (SRPM) was developed to simulate stormwater runoff and the associated pollutant loads occurring in catchments containing both urban and agricultural areas. The model operates on a hourly time step and can simulate hydrographs and pollutographs on both a storm event and a long-term bases. SRPM was written in FORTRAN and can be executed on both DOS and UNIX operating environment.

SRPM was tested and validated on a small catchment area north of Lake Okeechobee. Model simulation results were compared against field observations as well as CREAMS-WT predictions for a 33-month period. Statistical correlation analyses indicated that both models performed well in simulating daily, monthly and annual runoff and phosphorus loads. Given appropriate parameters, SRPM could also provide good estimate of hydrographs and pollutographs on an hourly basis. The model could be applied to a larger drainage basin for predicting runoff and associated pollutant loads for water resources planning and management.

Sensitivity analyses were conducted for key parameters to examine the effects of changes of model parameters on hydrographs and pollutographs during a storm as well as total runoff volume and phosphorus loads for the whole study period. The sensitivity analysis results indicated that runoff hydrographs and pollutographs were very sensitive to the Manning roughness constant. A reduction of above 110% was observed in the peak of hydrographs or pollutographs as the roughness constant was increased from 0.01 to 0.03. These results suggested that watershed surface characteristics play an important role in preventing or increasing flooding and water quality pollution problems (Greene and Cruise 1995). Both the roughness constant and the maximum depression depth were sensitive to total runoff volume. A slight sensitivity to the hydrograph was observed for the depression depth parameter. The results of the sensitivity analyses also showed that the maximum buildup value and the buildup rate were more sensitive to total phosphorus loads than to the pollutograph occurring in a storm while the washoff coefficient or the washoff power factor was sensitive to both the pollutograph and the total phosphorus loads.

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Table 1. Statistics of Observed and Predicted Daily Runoff and Phosphorus Loads from CREAMS-WT and SRPM

Statistics Analysis	Runoff (cm)			Phosphorus Load (kg/ha)		
	OBSERVED	CREAMS-WT	SRPM	OBSERVED	CREAMS-WT	SRPM
Mean	0.053	0.052	0.053	0.003	0.003	0.003
Standard Deviation	0.34	0.34	0.28	0.019	0.022	0.022
Standard Error	0.0107	0.0107	0.0088	0.0006	0.0007	0.0007
Sum	53.30	52.50	52.91	2.66	3.32	2.99
Minimum	0	0	0	0	0	0
Maximum	5.30	4.62	3.47	0.310	0.376	0.445
N	1005	1005	1005	1005	1005	1005
R^2	--	0.22	0.40	--	0.12	0.29
Regression Slope	--	0.47	0.52	--	0.42	0.65
Pearson Correlation Coefficient	--	0.47	0.63	--	0.34	0.54

Table 2. Statistics of Observed and Predicted Monthly Runoff and Phosphorus Loads from CREAMS-WT and SRPM

Statistics Analysis	Runoff (cm)			Phosphorus Load (kg/ha)		
	OBSERVED	CREAMS-WT	SRPM	OBSERVED	CREAMS-WT	SRPM
Mean	1.62	1.59	1.60	0.08	0.10	0.09
Standard Deviation	4.22	2.79	2.76	0.21	0.17	0.18
Standard Error	0.735	0.486	0.480	0.037	0.030	0.031
Sum	53.30	52.50	52.91	2.66	3.32	2.99
Minimum	0	0	0	0	0	0
Maximum	19.15	10.87	11.55	0.76	0.66	0.68
N	33	33	33	33	33	33
R^2	--	0.84	0.72	--	0.58	0.83
Regression Slope	--	0.61	0.56	--	0.63	0.83
Pearson Correlation Coefficient	--	0.92	0.85	--	0.76	0.91

Table 3. Statistics of Observed and Predicted Annual Runoff and Phosphorus Loads from CREAMS-WT and SRPM

Statistics Analysis	Runoff (cm)			Phosphorus Load (kg/ha)		
	OBSERVED	CREAMS-WT	SRPM	OBSERVED	CREAMS-WT	SRPM
Mean	17.77	17.50	17.64	0.89	1.11	1.00
Standard Deviation	17.19	10.32	9.08	0.69	0.67	0.42
Standard Error	9.92	5.96	5.24	0.40	0.39	0.24
Sum	53.30	52.50	52.91	2.66	3.32	2.99
Minimum	7.03	8.74	9.50	0.33	0.60	0.75
Maximum	37.59	28.88	27.43	1.66	1.87	1.48
N	3	3	3	3	3	3
R^2	--	0.94	0.90	--	0.99	0.93
Regression Slope	--	0.58	0.50	--	0.97	0.58
Pearson Correlation Coefficient	--	0.97	0.95	--	0.99	0.96

FIGURE CAPTIONS

Fig. 1. Observed and Simulated Daily Results from CREAMS-WT and SRPM during the period from 04/01/89 to 12/31/91: (a) Runoff; and (b) Phosphorus Loads

Fig. 2. Observed and Simulated Monthly Results from CREAMS-WT and SRPM during the period from April 1989 to December 1991: (a) Runoff; and (b) Phosphorus Loads

Fig. 3. Observed and Simulated Annual Results from CREAMS-WT and SRPM from 1989 to 1991: (a) Runoff; and (b) Phosphorus Loads (note: 1989 data starts in April)

Fig. 4. Sensitivity Analyses Results - Runoff Hydrographs Response to Changes in Manning Roughness Constant, Maximum Depression Depth, and ET Coefficient: (a) Manning Roughness Constant; (b) Maximum Depression Depth; and (c) ET Coefficient

Fig. 5. Sensitivity Analyses Results - Phosphorus Load Pollutographs Response to Changes in Maximum Buildup Value, Buildup Rate, Washoff Coefficient, and Washoff Power Factor: (a) Maximum Buildup Value; (b) Buildup Rate; (c) Washoff Coefficient; and (d) Washoff Power Factor

Fig. 6. Sensitivity Analyses Results - Total Runoff/Total Phosphorus Loads Response to Key Hydrology/Water Quality Parameters: (a) Key Hydrology Parameters; and (b) Key Water Quality Parameters

Fig. 1(a)

Observed and Simulated Daily Runoff

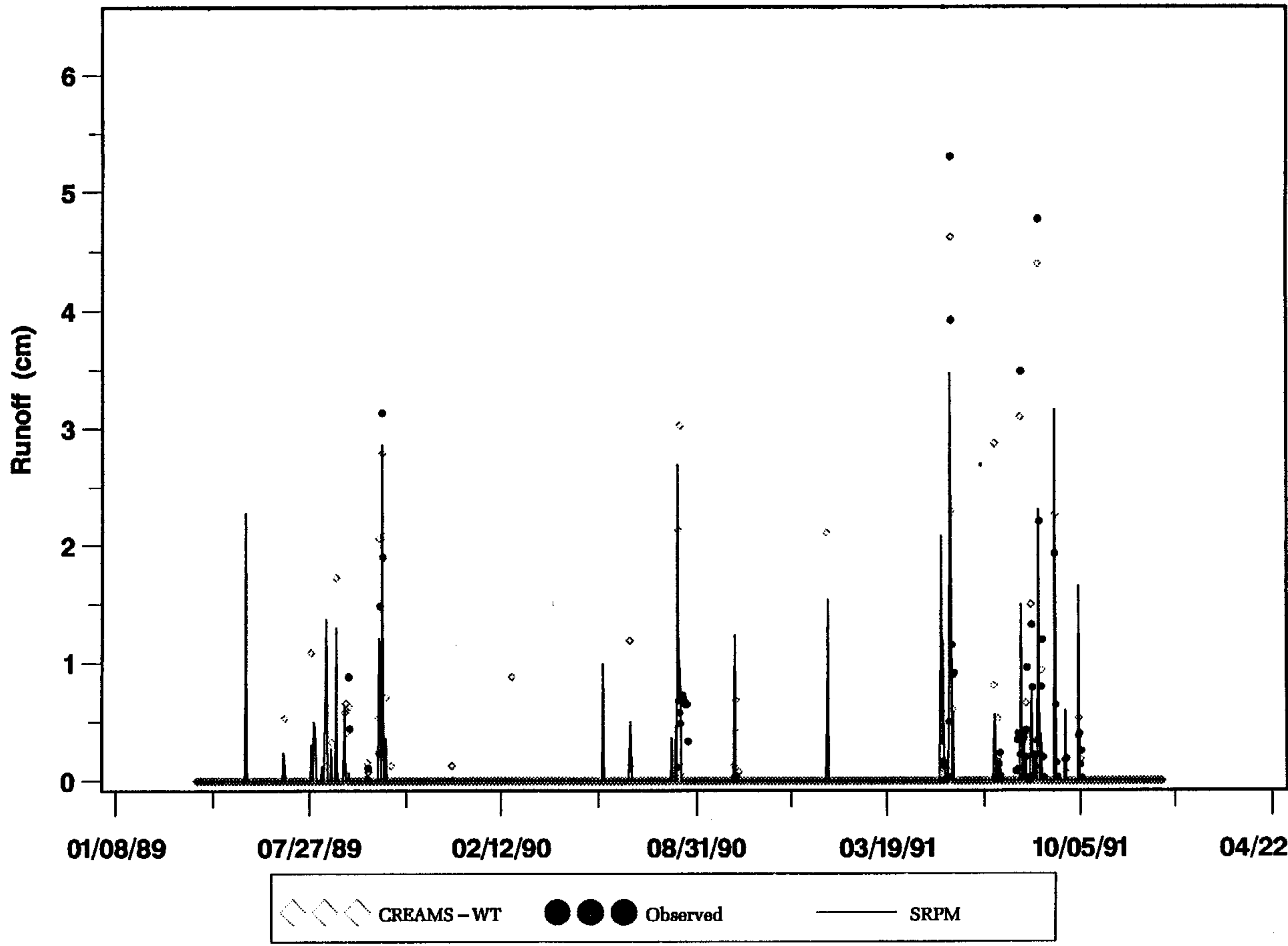


Fig 1(c)

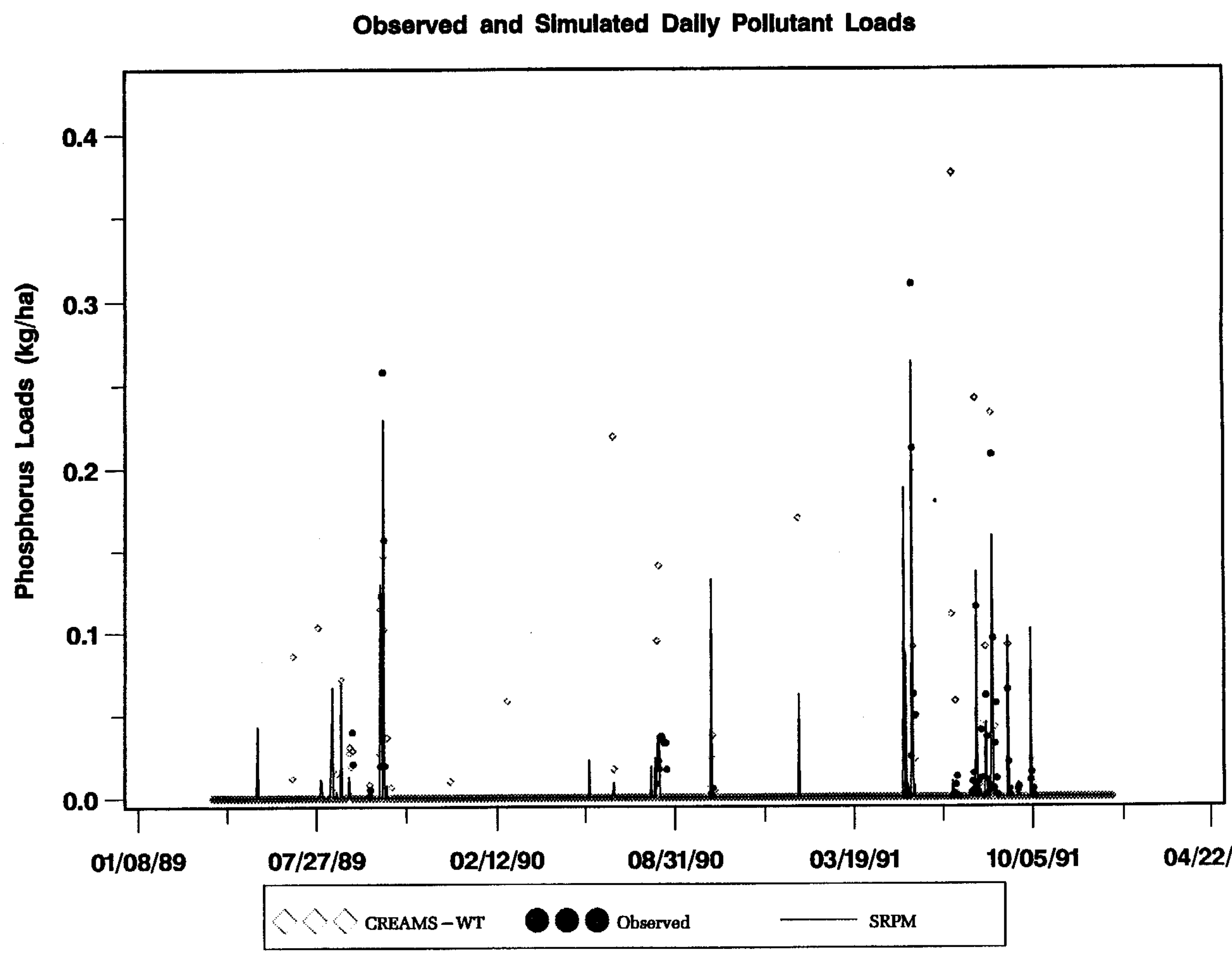
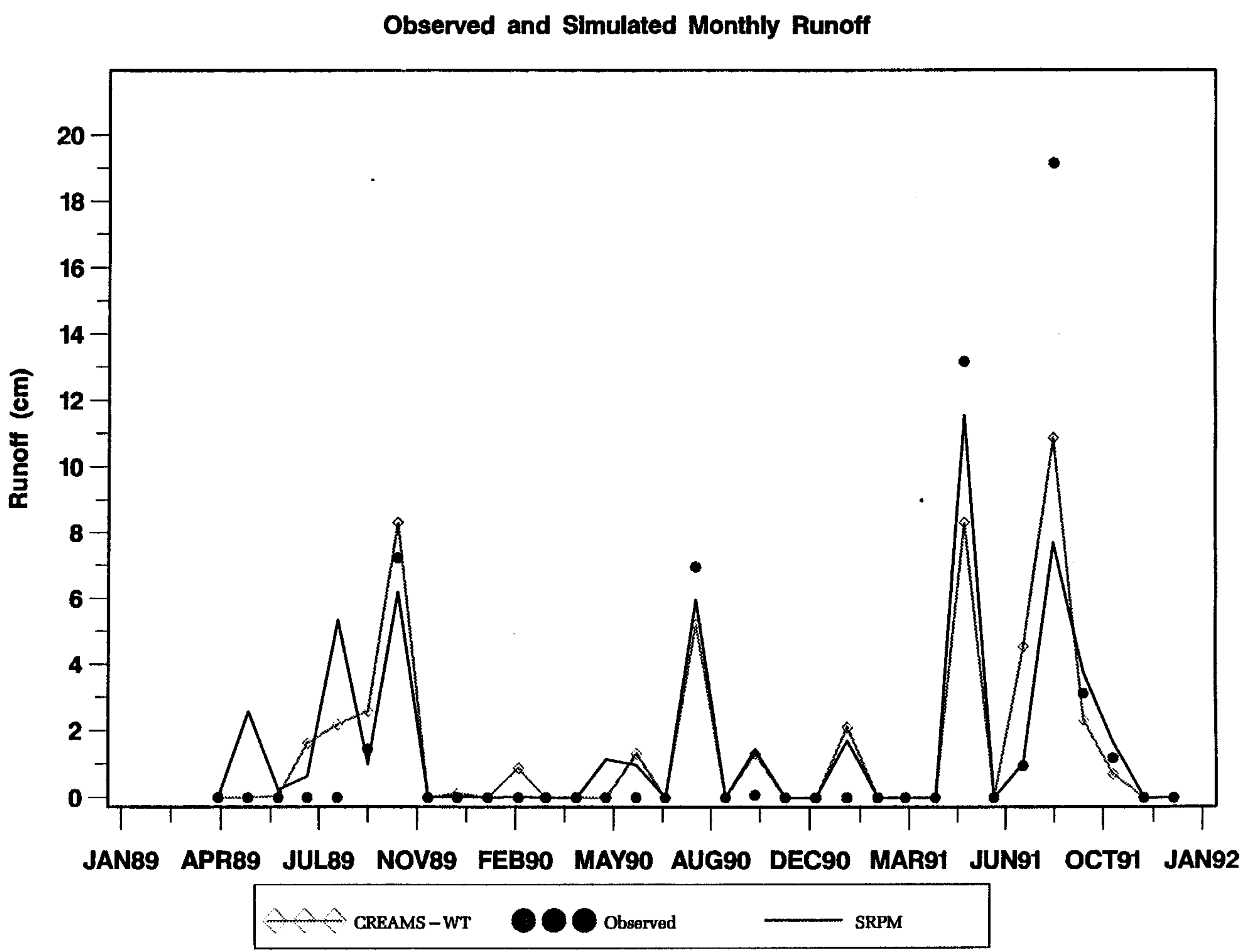

Observed and Simulated Daily Pollutant Loads
Phosphorus Loads (kg/ha)
0.4
0.3
0.2
0.1
0.0
01/08/89
07/27/89
02/12/90
08/31/90
03/19/91
10/05/91
04/22/92
CREAMS-WT
Observed
SRPM

Fig. 2(a)


Observed and Simulated Monthly Runoff
Runoff (cm)
0
2
4
6
8
10
12
14
16
18
20
JAN89
APR89
JUL89
NOV89
FEB90
MAY90
AUG90
DEC90
MAR91
JUN91
OCT91
JAN92
CREAMS-WT
Observed
SRPM

Observed and Simulated Monthly Pollutant Loads

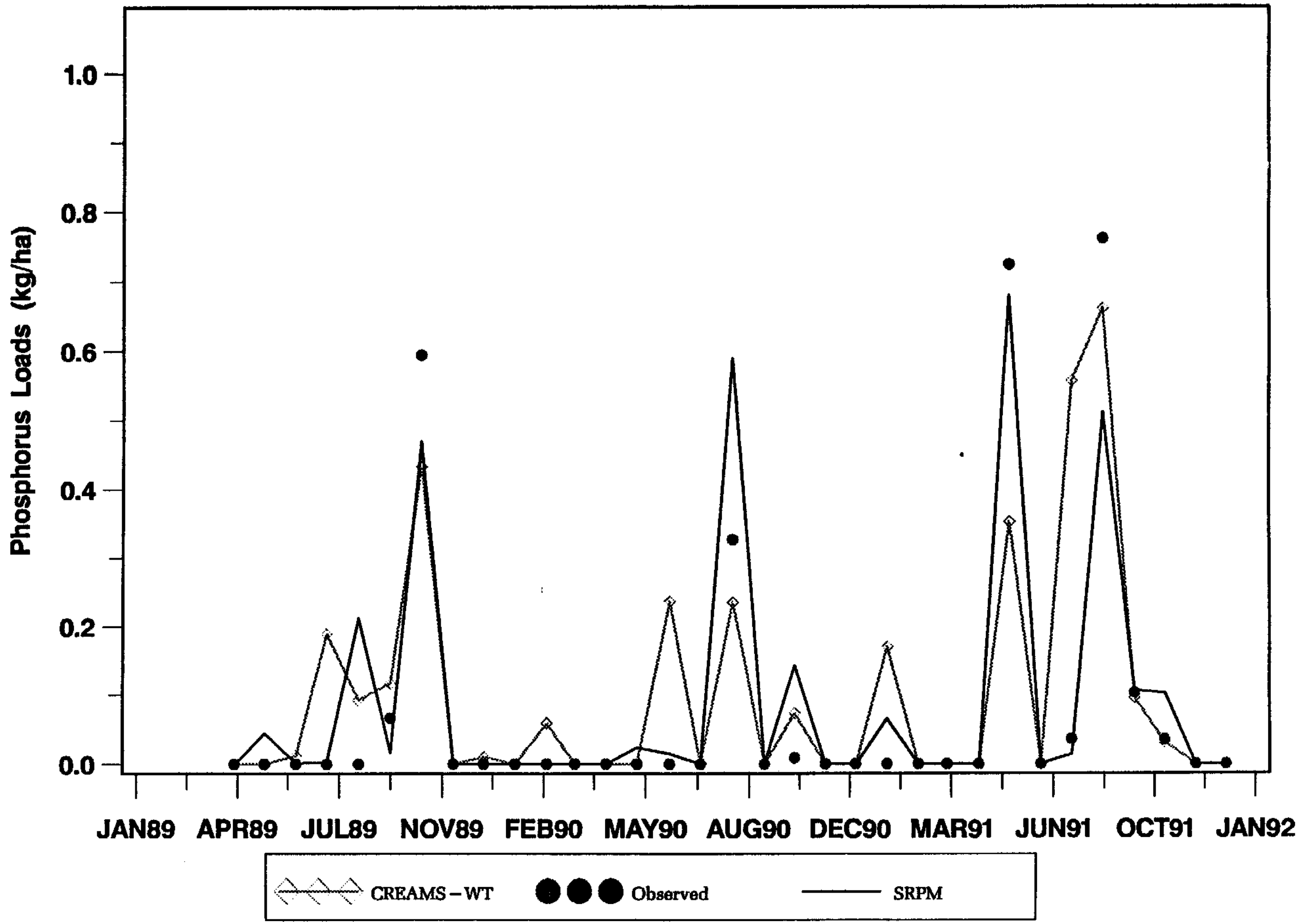
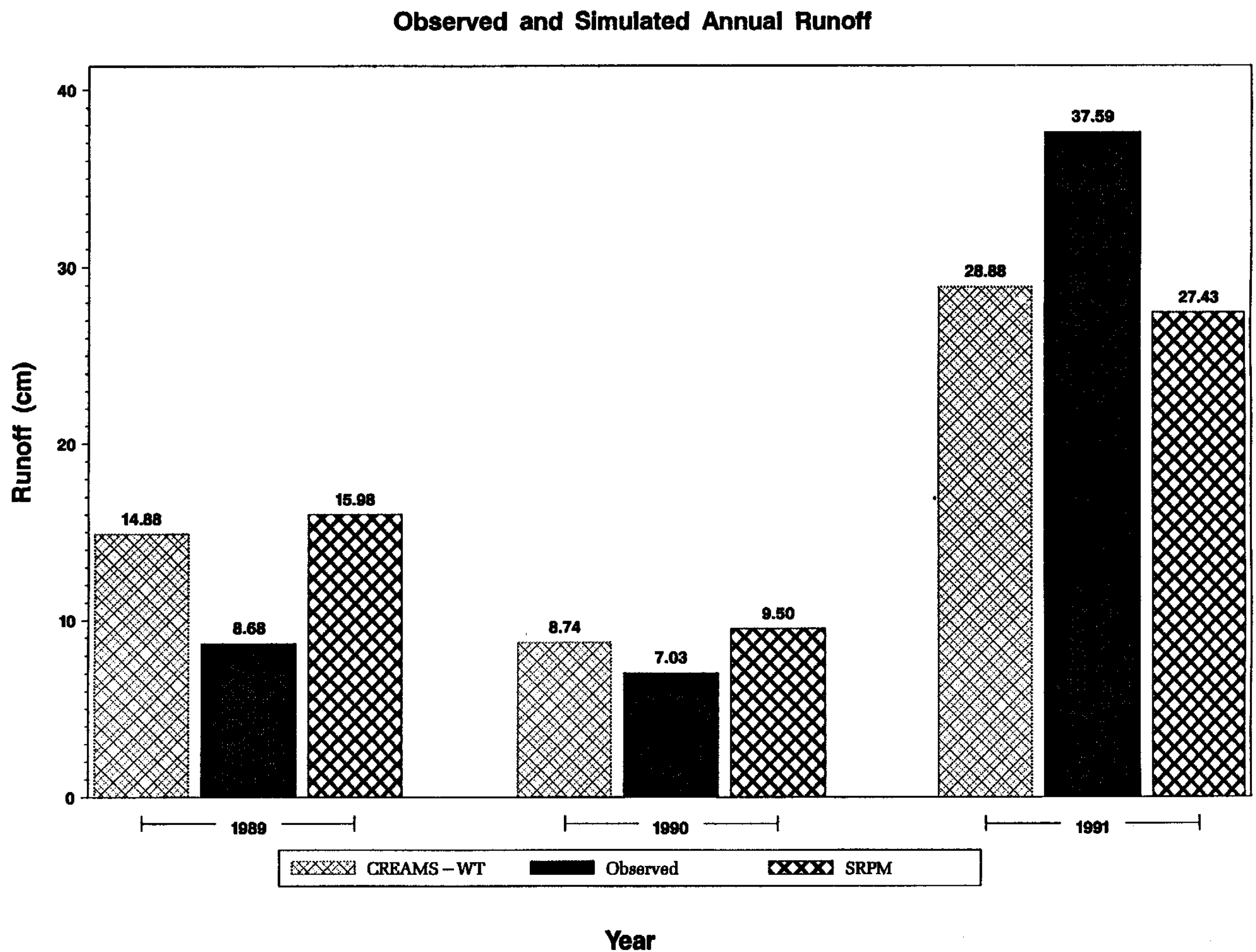


Fig. 2(c)

Fig. 3 (a)


Observed and Simulated Annual Runoff
Runoff (cm)
0
10
20
30
40
14.88
8.68
15.98
8.74
7.03
9.50
28.88
37.59
27.43
1989
1990
1991
CREAMS – WT
Observed
SRPM
Year

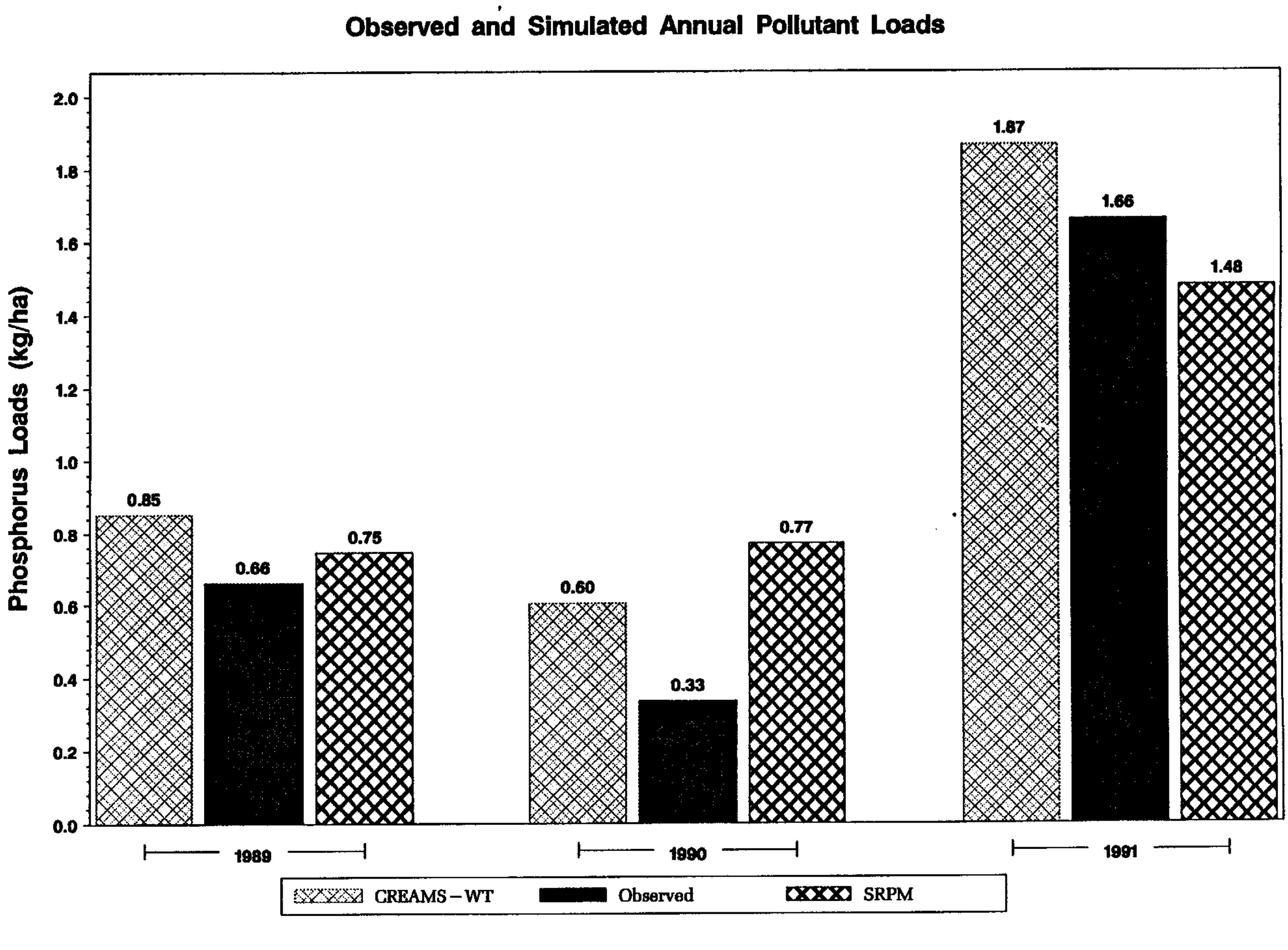

Observed and Simulated Annual Pollutant Loads
Phosphorus Loads (kg/ha)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.85
0.66
0.75
0.60
0.33
0.77
1.87
1.66
1.48
1989
1990
1991
CREAMS – WT
Observed
SRPM
Year

Fig. 3(b)

Simulated Hourly Runoff
(Lake Okeechobee Watershed – W. F. Rucks Site)

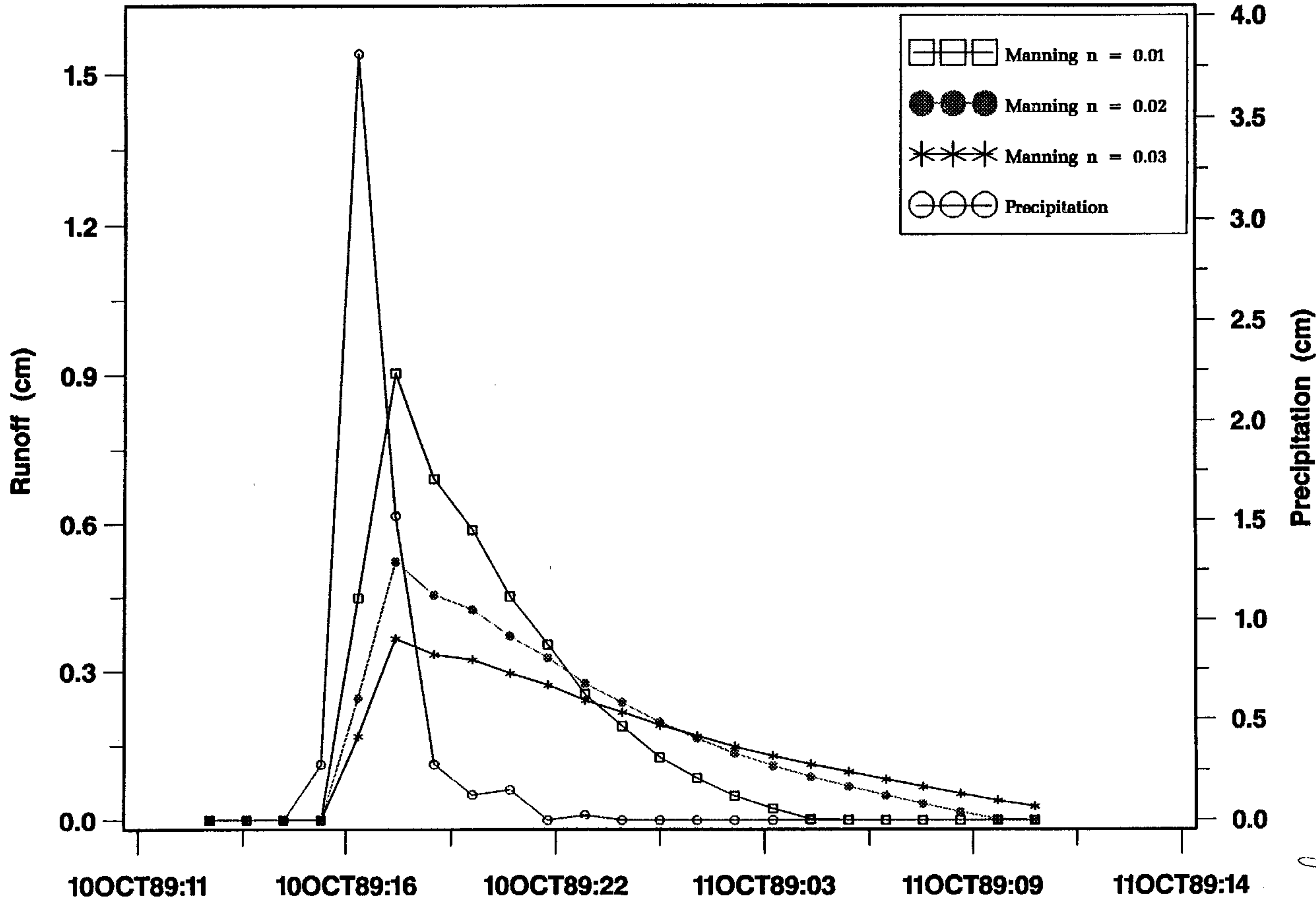


Fig. 4(c)

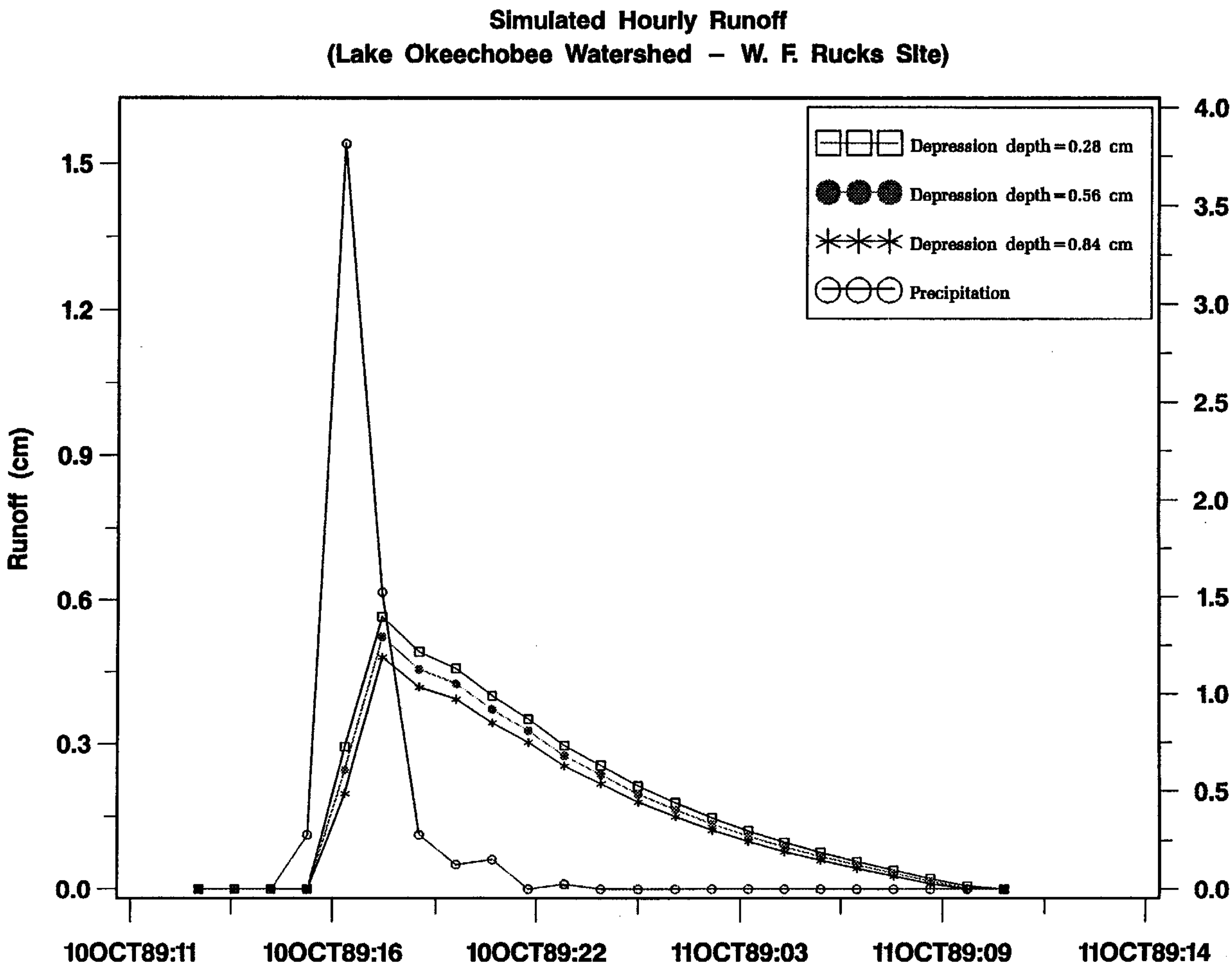
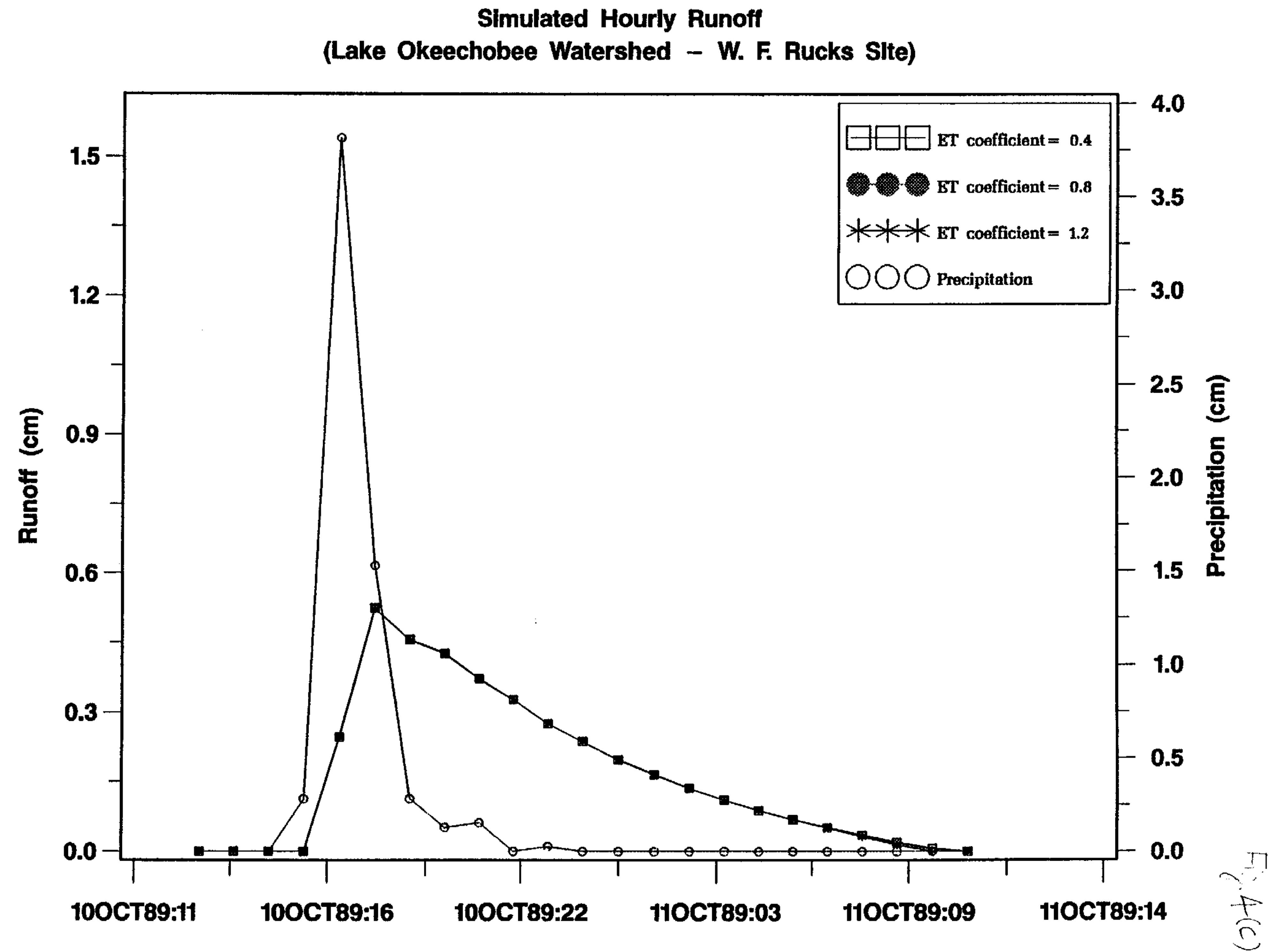
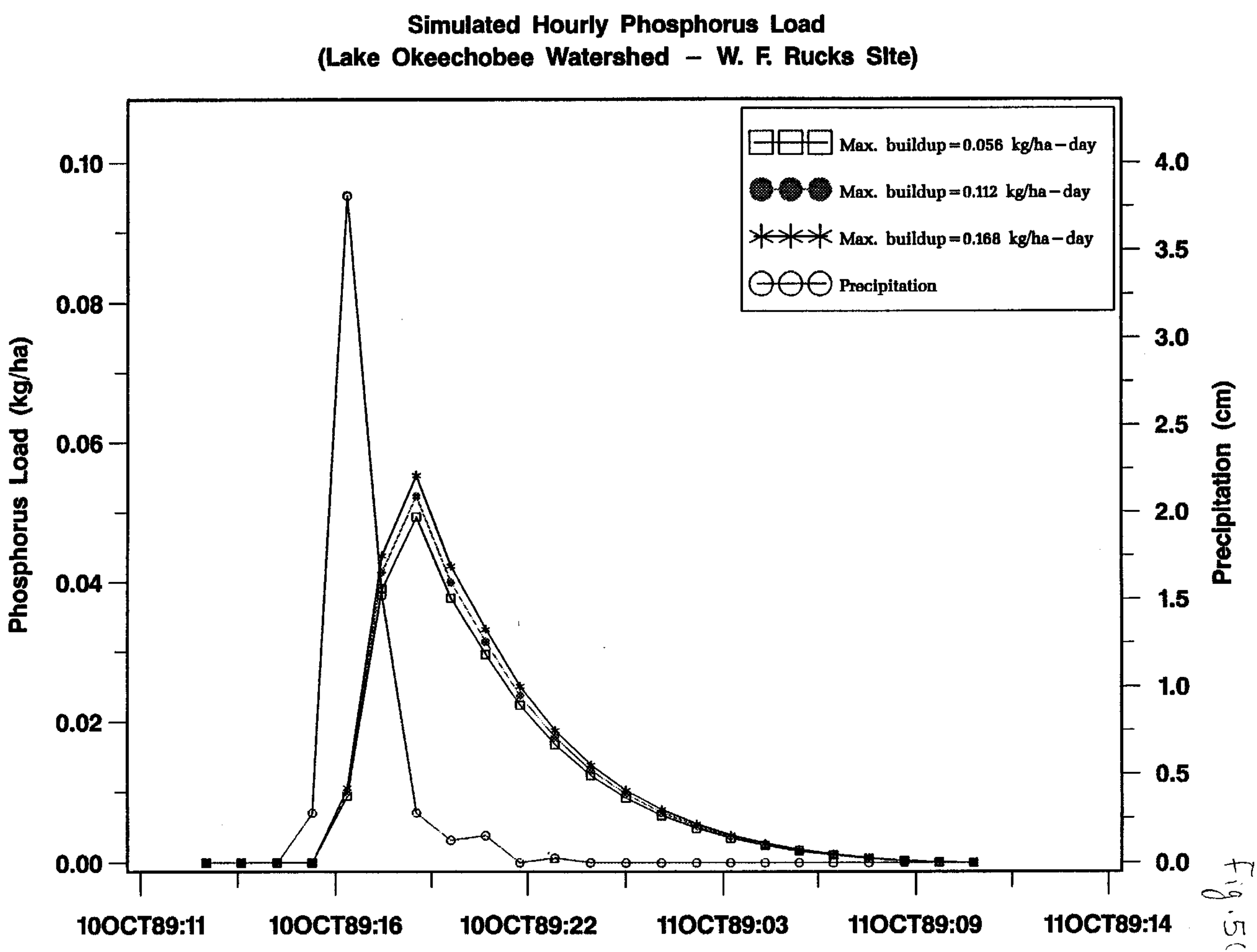

Simulated Hourly Runoff
(Lake Okeechobee Watershed – W. F. Rucks Site)
Runoff (cm)
Precipitation (cm)
1.5
1.2
0.9
0.6
0.3
0.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Depression depth = 0.28 cm
Depression depth = 0.56 cm
Depression depth = 0.84 cm
Precipitation
10OCT89:11
10OCT89:16
10OCT89:22
11OCT89:03
11OCT89:09
11OCT89:14

Fig. 40

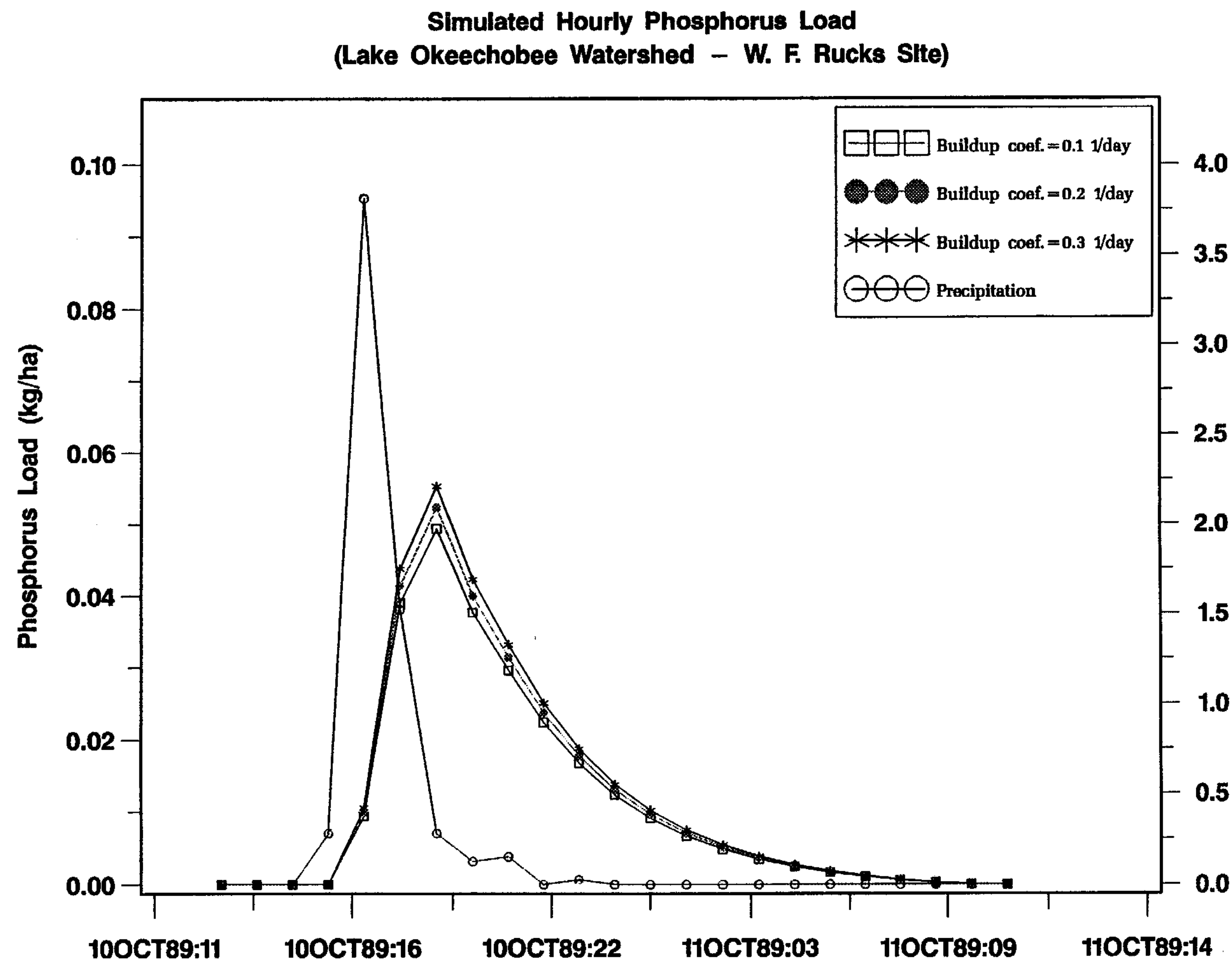


Simulated Hourly Runoff
(Lake Okeechobee Watershed -- W. F. Rucks Site)
Runoff (cm)
Precipitation (cm)
ET coefficient = 0.4
ET coefficient = 0.8
ET coefficient = 1.2
Precipitation
0.0
0.3
0.6
0.9
1.2
1.5
0.5
1.0
2.0
2.5
3.0
3.5
4.0
10OCT89:11
10OCT89:16
10OCT89:22
11OCT89:03
11OCT89:09
11OCT89:14
Fig. 4(c)



Simulated Hourly Phosphorus Load
(Lake Okeechobee Watershed – W. F. Rucks Site)
Max. buildup=0.056 kg/ha–day
Max. buildup=0.112 kg/ha–day
Max. buildup=0.168 kg/ha–day
Precipitation
Phosphorus Load (kg/ha)
Precipitation (cm)
0.10
0.08
0.06
0.04
0.02
0.00
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10OCT89:11
10OCT89:16
10OCT89:22
11OCT89:03
11OCT89:09
11OCT89:14

Fig. 5(a)



Simulated Hourly Phosphorus Load
(Lake Okeechobee Watershed – W. F. Rucks Site)
Buildup coef. =0.1 1/day
Buildup coef. =0.2 1/day
Buildup coef. =0.3 1/day
Precipitation
Phosphorus Load (kg/ha)
0.10
0.08
0.06
0.04
0.02
0.00
Precipitation (cm)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10OCT89:11
10OCT89:16
10OCT89:22
11OCT89:03
11OCT89:09
11OCT89:14
Fig. 50

Simulated Hourly Phosphorus Load
(Lake Okeechobee Watershed – W. F. Rucks Site)

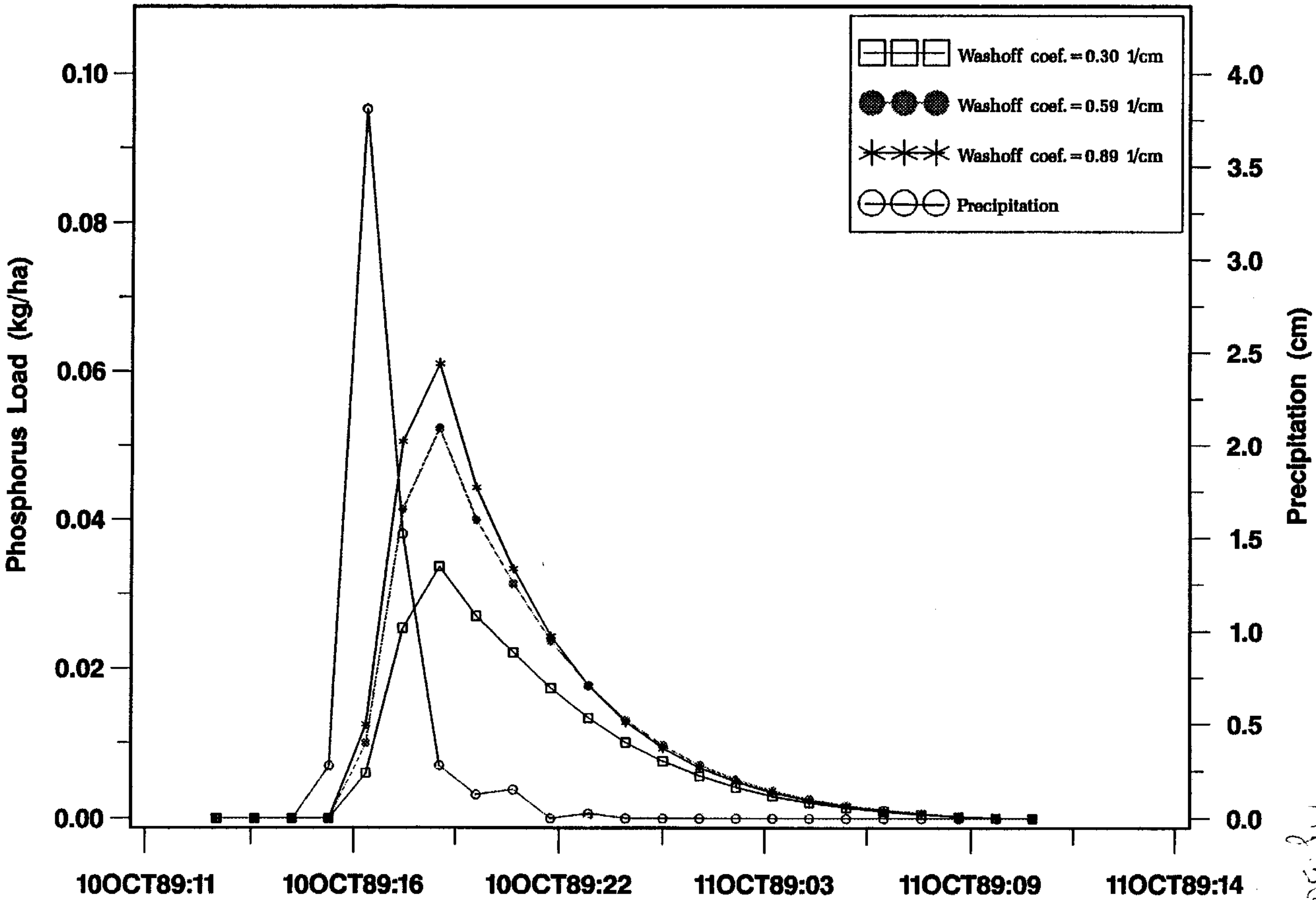


Fig. 5(c)

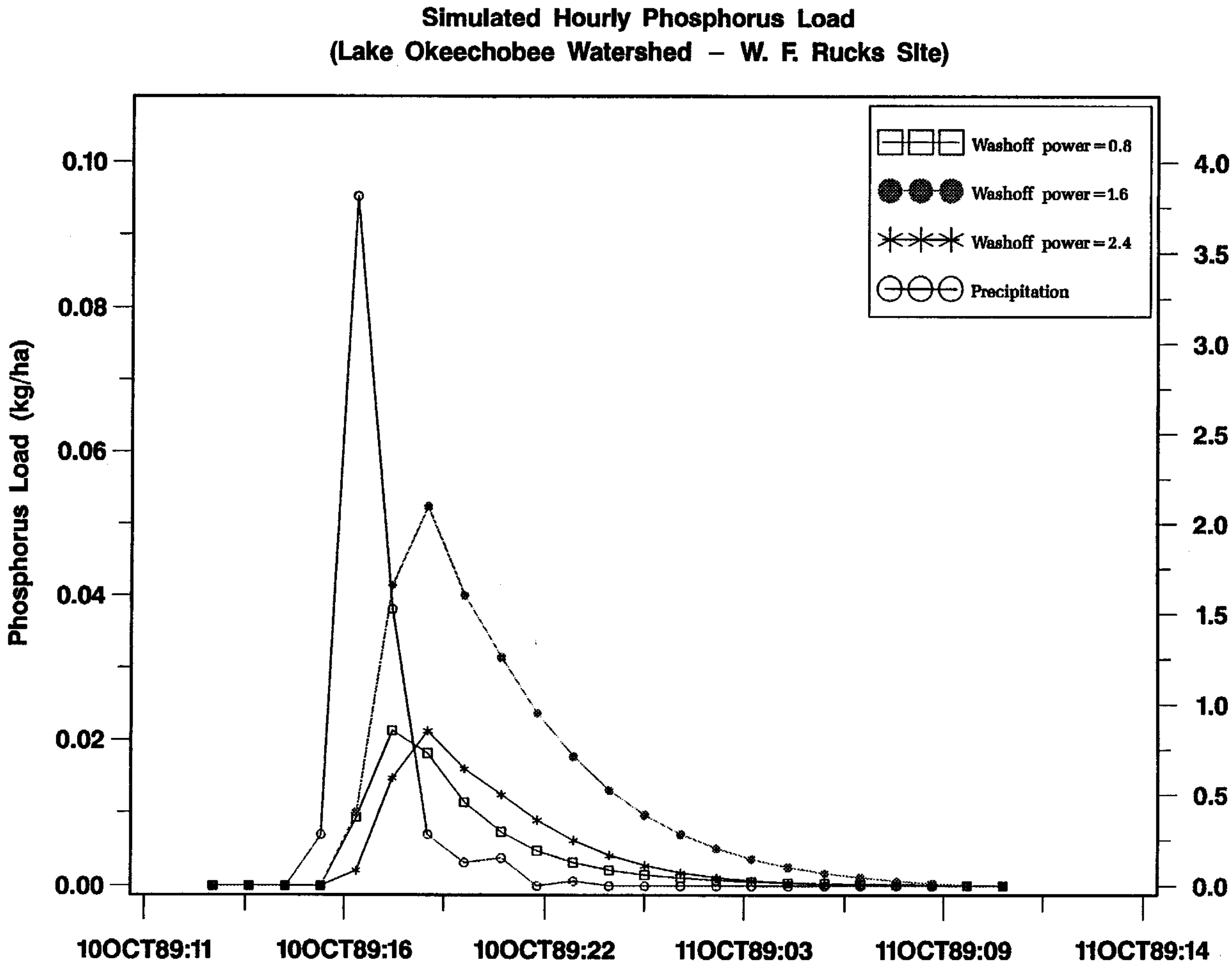

Simulated Hourly Phosphorus Load
(Lake Okeechobee Watershed – W. F. Rucks Site)
Washoff power=0.8
Washoff power=1.6
Washoff power=2.4
Precipitation
Phosphorus Load (kg/ha)
Precipitation (cm)
0.10
0.08
0.06
0.04
0.02
0.00
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10OCT89:11
10OCT89:16
10OCT89:22
11OCT89:03
11OCT89:09
11OCT89:14

Fig. 5(

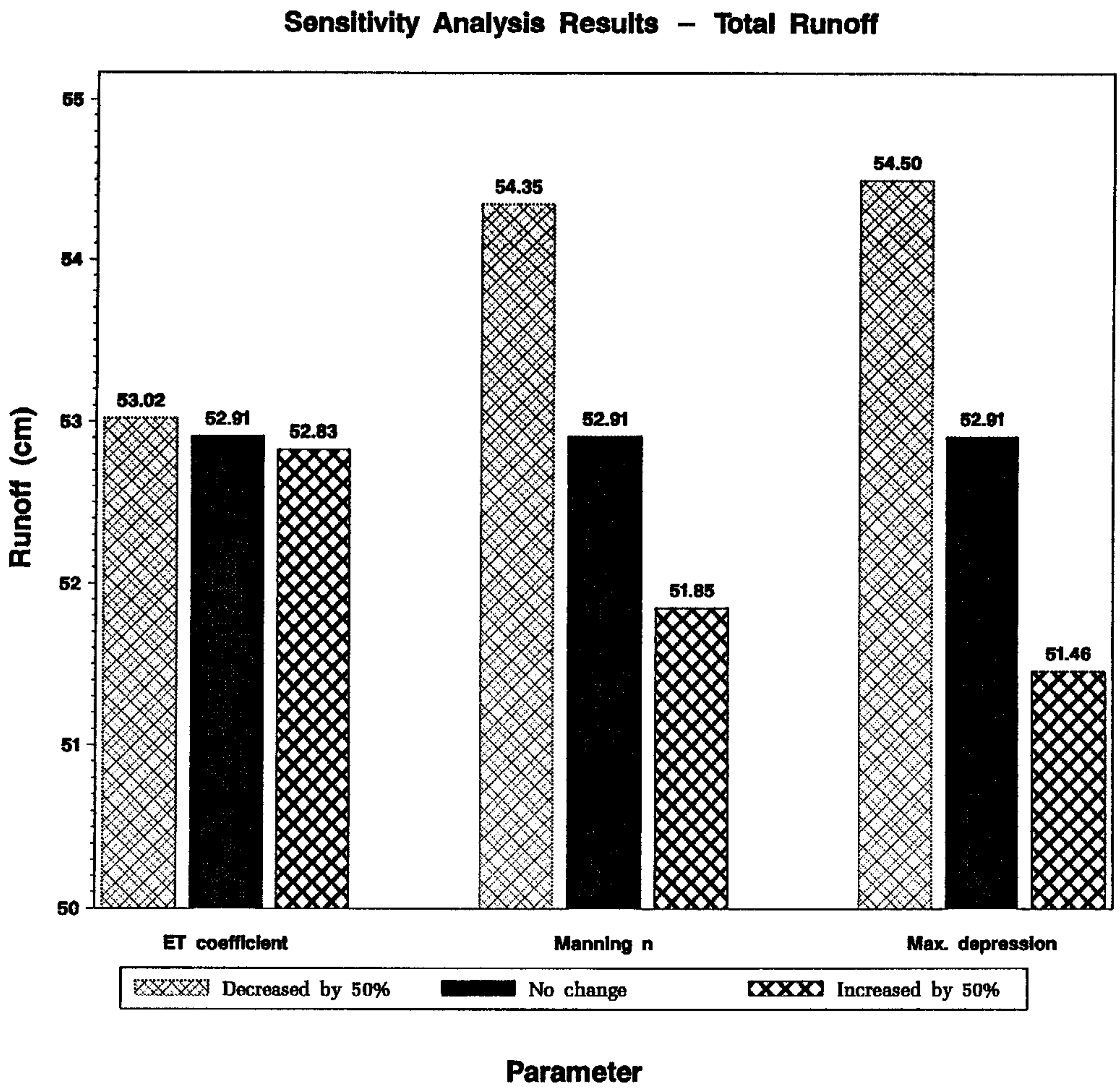

Sensitivity Analysis Results – Total Runoff
Runoff (cm)
55
54
53
52
51
50
53.02
52.91
52.83
54.35
52.91
51.85
54.50
52.91
51.46
ET coefficient
Manning n
Max. depression
Decreased by 50%
No change
Increased by 50%
Parameter

Fig. 6(a

Fig. 6(b)

Sensitivity Analysis Results – Total Phosphorus Loads